is almost as perfect as any projection can give separately. The same is true of the East Indies and Australia. Africa, though good, suffers a little in shape by having all its parallels concave to the north.

It will be observed that on the land areas the departure from right-angularity is so slight that a scale of miles can be used quite as well as upon any ordinary continental map. This is a rare quality in a world map; a great virtue.

The projection lends itself to all manner of areal distributions—in geology, paleontology, meteorology, climatology, botany, zoology, anthropology, and ethnology—where continental space relationship is important.

Where ocean unity is more important than continental unity, the projection lends itself quite as readily to the deployment of the oceans radially from the South Pole.

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EDITORIAL NOTE

The editor wishes to call attention to a series of four papers printed in the March, 1929, number of the Geographical Journal, London, as follows:

(1) A New Equal-Area Projection for World Maps, by S. Whittemore Boggs.

(2) A Retro-Azimuthal Equidistant Projection for the World Sphere, by Arthur R. Hinks.

(3) A Chart Showing the True Bearing of Rugby from all Parts of the World, by E. A. Reeves, map curator Royal Geographic Society.

(4) An Oblique Mollweide Projection of the Sphere, by Col. Sir Charles Close, president Royal Geographic Society.

The first of these papers describes a new equal-area projection which should be useful for statistical purposes. The map is an equal-area projection partaking of the qualities both of the equal-area projection of Sanson and the elliptical equal-area projection of Mollweide and being somewhat an improvement on both. The angular distortion is less than in Sanson below latitude 62° and less than Mollweide above 68°.

The projection is described by the author as follows:

> Since a flat map can not be made to represent the shape of large portions of the earth's surface perfectly, no name has heretofore been given to the property of good representation. The term "eumorphism" might, however, be appropriately applied to connote good shape of areas, just as orthomorphism is used to signify true shape in small areas. Eumorphism (i. e., approximate orthomorphism in large areas) would be characterized by approximation to rectilinear intersection of parallels and meridians and by the approximation to equality of linear scales along the parallels and meridians or along all parallels and at least a central meridian.

The second paper, by Mr. Hinks, had its beginnings in the invention by Mr. J. I. Craig of the Egyptian Survey of a projection which showed the azimuth of Mecca at any point on a map of the Muhammadan East, thus opening up a new class of projections, the retro-azimuthal, which preserve the true azimuth of any point from the center of projection. The retro-azimuthal, on the contrary give the true azimuth of the center from any point, a quality useful to the Muslim in showing the bearing he should assume for his prostration to Mecca, and to the surveyor in giving the azimuth on which he must set his frame aerial to get a distant station sending time signals.

The third paper, by Mr. Reeves, describes an effort to show the curves of Equal Reverse Azimuth of Rugby and so to produce a chart somewhat similar in general appearance to the Admiralty chart of the world showing Curves of Equal Magnetic Variation, but giving the true bearing of Rugby from all parts of the world instead of showing the variation of the compass.

The fourth paper, by Col. Sir Charles Close, is largely mathematical in which the author has computed the coordinates of a network for meridians and parallels at every 30°.

For the details of the paper the reader must be referred to the original.—*A. J. H.*

WET AND DRY NORTHERS

551.55 (73)

By I. R. TANNEHILL

[Weather Bureau office, Galveston, Tex., April 1, 1929]

There has been considerable discussion of the term "norther." In the northern half of the country the severe cold wave is called a "blizzard" but in the parlance of seafaring men it is a "northwester." In the south, even among seamen, a cold wind from a northerly quarter is commonly referred to as a "norther." Some early voyagers over Central American waters termed them "norths." (1) There is undoubtedly a sound basis for this distinction. The average path of cyclones and anticyclones determines largely the frequency of winds from northwest and north. As a result, northwest winds are more frequent in the northern half of the country than those from the north, while in the south the true "norther" predominates.

Cyclonic depressions, passing over or near the northern locality, with considerable frequency, cause northwest winds in their rear, quickly giving way as a rule to the variable or shifting winds with the passing of the center of the anticyclone. Winds from the north are of relatively short duration.

The change of wind to a northerly quarter in southern sections is produced mostly by the southward drift of anticyclones which form or follow in the wake of the depression. As the anticyclone drifts eastward or southeastward with center to the northward, the winds change more slowly from northwest to northeast and the duration of winds from true north is therefore much greater than in northern districts.

In the Annual Report of the Chief of the Weather Bureau, 1896–97, pages 110–123, there appears a record of average duration of wind from eight points of the compass for a 5-year period, 1891–95, inclusive. From this record I have computed the ratios of durations of north to northwest winds for a number of stations and these are shown in Figure 1. The geographical distribution of these ratios is evidence of the relatively greater frequency of true north winds in southern latitudes. On the Pacific coast the prevailing westerly wind obscures the effect of average cyclonic travel but east of the Rockies it is clearly seen. The greatest frequency, relatively, of north winds is found on the middle Gulf coast where the east/west contour of the coast line is evidently an added influence favoring winds from true north.

It is probable that this high frequency of true north winds is prevalent in the winter season over the whole of the Gulf of Mexico, the western Caribbean Sea, and much of the adjacent land areas. Over this region the term "norther" is commonly used (2) since it more accurately describes the wind than the name "northwester" used in higher latitudes.[1] It is used in some parts of California.

In Texas, especially in the interior, marked changes in temperature attend the norther. The depression preceding it sometimes causes abnormally high day temperatures before the wind shifts and thus the diurnal drop in temperature, normally large in the interior, is added to the change produced by the norther. While these changes are frequently sudden and marked in extent, they are not more so than in many other parts of the country (3).

It is typical of the severe norther moving into Texas that fair weather seems assured. Commonly the weather is fair but it is impossible to determine the percentage of them with rain because it is not possible to make an accurate count of northers. They may include every wind from a northerly quarter, light or strong, and the temperature change may be slight or excessive. The weather in this region is apparently dominated by a high-pressure area, usually, and when the norther is severe the anticyclone is of marked strength. Precipitation is indicated with the advent of the norther, perhaps, but fair weather is usually expected to follow.

From an agricultural standpoint it is quite important to know whether the norther will be wet or dry. If dry, with clear skies, killing frosts form when the wind diminishes and abnormally low temperatures occur in localities favoring radiation. Livestock suffer severely when the wind is accompanied by rain, sleet, or snow. Little shelter is afforded on the Texas coastal plains and thousands of cattle and other livestock have perished in wet northers.

The amount of fuel consumed in heating depends upon the character of the weather as well as the temperature. When cold and wet, the majority of persons remain in their homes. When the norther is dry, outdoor activities, places of entertainment, and public gatherings of various kinds draw many from their homes and less fuel is consumed. In many other ways it is of interest, and rarely is a norther forecast by the Weather Bureau that this question is not asked many times: Will it be wet or dry?

In many instances the sky clears with the arrival of the wind, promising fair weather, to be followed in a few hours to a day by increasing cloudiness and then rain, snow, or sleet, sometimes persisting for several days.

The difficulties encountered in forecasting the occurrence of precipitation in connection with Texas northers are many. The following discussion relates to the frequency of precipitation attending northers and attempts to define the antecedent pressure conditions differentiating the wet from the dry norther. The relation of temperature to probability of precipitation is shown and a description of a few of the more severe northers is included.

Some severe wet northers.—When the temperature is near the freezing point and precipitation continues for a period of 48 hours or more in the coastal region of Texas considerable losses of livestock are probable. Over extensive areas there is little natural shelter and the normal mildness of the winters is responsible for the prevailing lack of artificial shelter. In the most severe type, sleet and snow occur and occasionally rain freezes as it falls, producing a glaze and an accumulation of ice upon telegraph, telephone, and electric railway lines seriously impeding or interrupting transportation and communication. Electric light and power lines suffer equally.

A careful examination of the records of wet northers at Galveston during the 25-year period, 1901 to 1925, shows that such conditions occur infrequently. Limiting the number to those in which two or more consecutive days with temperature at or below freezing and precipitation were recorded, there were only seven. The dates of these and the attendant weather conditions are shown in Table 1.

TABLE 1.—*Weather conditions in seven severe wet northers at Galveston*

Initial date		Feb. 4, 1905	Jan. 6, 1912	Feb. 24, 1914	Jan. 14, 1917	Feb. 4, 1923	Dec. 19, 1924	Dec. 28, 1925
Conditions on first day.	Precipitation	0.18	0.12	0.37	T.	2.15	0.68	0.01
	Minimum temperature	29	30	27	32	31	30	26
	Other	I.	St. S.	St. S.	S.	------	.12	St. S.
On second day.	Precipitation	T.	.28	.03	T.	.01		.09
	Minimum temperature	32	29	28	32	29	28	27
	Other	------	------	S.	------	St. I.	St. I.	I.
On third day.	Precipitation	------	------	------	------	------	.06	------
	Minimum temperature	------	------	------	------	------	28	------
	Other	------	------	------	------	------	St. I.	------
On fourth day.	Precipitation	------	------	------	------	------	.08	------
	Minimum temperature	------	------	------	------	------	32	------
	Other	------	------	------	------	------	------	------

T. Trace of precipitation. St. Sleet. S. Snow. I. Rain freezing. Precipitation in inches and hundredths. Minimum temperature Farenheit.

Sleet, snow, or rain freezing as it fell accompanied six of these northers. The most severe was that of December, 1924, when there were four consecutive days with precipitation and temperatures freezing or below; sleet, snow, and glaze were recorded.

FIGURE 1.—Ratios, in percentage, of duration of north to northwest winds, average annual, years 1891–1895, inclusive, at a representative group of stations; that is, the entry 87 at Memphis indicates that the north winds averaged annually 87 per cent of the northwest winds in duration. Along the Gulf coast, north winds are more frequent than winds from the northwest

On December 20, 1924, telephone and telegraph services failed almost completely in this section, interurban cars ceased running, and thousands of cattle perished. In some sections the cold combined with other conditions was the worst since 1895. The State weather summary (4) included the following:

> The month was generally unfavorable to agricultural interests, due to insufficient moisture, in western and central Texas and to the severe freezes after the 18th, which killed all tender vegetation and did considerable damage to hardy truck, oats, young citrus trees, and lesser damage to citrus fruits on trees. * * * Cattle losses were heavy in the coastal section where the cold wave of the 18th and 19th was attended by a heavy fall of sleet and freezing rain that remained on the ground for several days.

Precipitation with temperatures 40° or below continued at Galveston for seven consecutive days. In this respect also it exceeded all other records in the 25-year period. The nearest approach was in February,

[1] A description of northers in the Gulfs of Mexico and Tehuantepec and in the Canal Zone by Willis E. Hurd appeared on the reverse of the Central American Pilot Chart for February, 1927.

1905, when there were six consecutive days with precipitation and minimum temperatures 40° or lower.

The records of five wet northers in which the temperature was 40° or lower with precipitation on four or more consecutive days is shown in Table 2.

TABLE 2.—*Minimum temperature and precipitation daily in wet northers with four or more consecutive days 40° or below and precipitation*

Initial date		Jan. 26, 1902	Feb. 3, 1905	Jan. 13, 1917	Dec. 19, 1924	Dec. 28, 1925
First day	Minimum temperature	36	34	35	30	26
	Precipitation	.02	.09	.02	.68	.01
Second day	Minimum temperature	32	29	32	28	27
	Precipitation	.13	.18	T.	.12	.09
Third day	Minimum temperature	33	32	32	28	33
	Precipitation	.09	T.	T.	.06	.90
Fourth day	Minimum temperature	37	34	37	32	39
	Precipitation	.30	T.	T.	.08	T.
Fifth day	Minimum temperature	39	36	37	40	------
	Precipitation	.12	.21	.01	T.	------
Sixth day	Minimum temperature	------	35	------	34	------
	Precipitation	------	.74	------	.27	------
Seventh day	Minimum temperature	------	------	------	30	------
	Precipitation	------	------	------	T.	------

T. Trace of precipitation—less than 0.01 inch.

Dry northers.—In the majority of cases rain accompanies or immediately precedes the arrival of the norther. Occasionally rain continues into the first day of freezing temperature when the norther is severe but it generally ceases with the fall in temperature and before the freezing point is reached. The latter class may be included with the dry northers. In the 25 years of record discussed, there have been four northers, in which the freezing temperature was reached, without precipitation either during the period of low temperature or for several days prior to its arrival. The record in this respect was in 1912. On February 4 of that year the temperature fell to 27° and there was no precipitation and there had been none since the 28th of January and none occurred until the 8th of February. Three other northers in this period, with minimum temperatures below freezing, were not accompanied by precipitation, and in these instances none had occurred during the three days preceding.

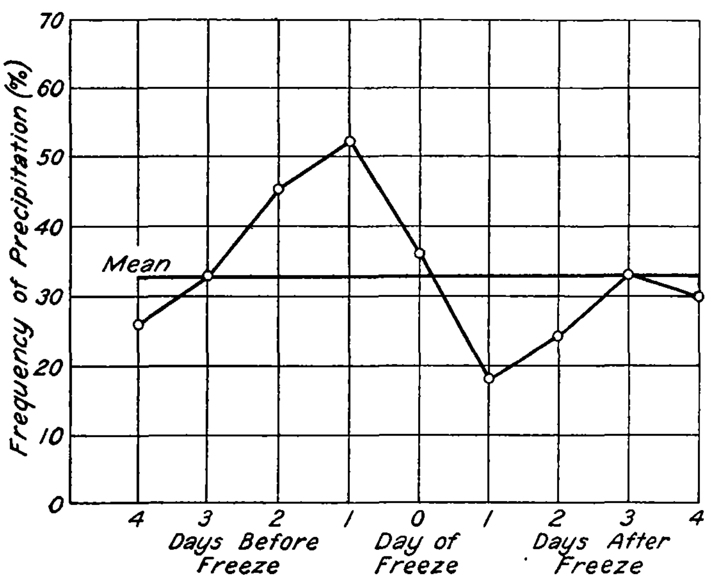

FIGURE 2.—Probability of precipitation, per cent, on days with a freeze, the four days prior to the freeze and the four days following the freeze. From 102 occurrences at Galveston, Tex., 1901 to 1925

There have been 12 northers with two or more consecutive days of freezing temperature unaccompanied by precipitation and these are listed in Table 3. Dates, minimum temperatures and occurrence of precipitation for these northers are shown there.

TABLE 3.—*Dry northers, with freezing temperature, in period 1901–1925 at Galveston, Tex.*

Initial date of freezing without rain	Minimum temperature on first day, second day, and third day (without precipitation)			Initial date of freezing without rain	Minimum temperature on first day, second day, and third day (without precipitation)		
Jan. 14, 1905 [1]	30	29	------	Dec. 8, 1917 [2]	30	31	------
Feb. 13, 1905 [1]	17	22	------	Dec. 29, 1917 [2]	31	26	------
Feb. 15, 1909 [1]	24	29	------	Dec. 21, 1916 [3]	32	26	------
Jan. 3, 1919 [1]	29	28	------	Jan. 5, 1924 [3]	32	26	32
Dec. 14, 1914 [1]	28	32	------	Dec. 22, 1925 [3]	31	32	------
Jan. 2, 1911 [2]	24	19	23	Feb. 4, 1912 [4]	27	28	------

[1] Preceded by 1 day with freezing temperature and precipitation.
[2] Rain on day preceding first with freezing temperature.
[3] No rain on 3 days immediately preceding first with freezing temperature.
[4] No rain on 6 days preceding occurrence of a minimum temperature at or below freezing.

Frequency of precipitation preceding and following freezes.—During the years 1901 to 1925 there were 102 days on which the minimum temperature, as an integer, was 32° or below.[1] For each of these 102 occurrences, the precipitation records were examined for the four days preceding and the four days following the freeze as well as the day of the freeze. The total number of occurrences of precipitation for each day of the period, beginning with the fourth day before and ending with the fourth day following the freeze, were as follows: 27, 33, 46, 53, 37, 18, 24, 34, and 31. Graphically the percentage probability of precipitation is shown in Figure 2.

Amounts of precipitation of 0.01 inch or more, as here tabulated, were most frequent on the day preceding the freeze, and least on the day following. The effect of average cyclonic travel is evident. A slight secondary maximum of frequency is indicated on the third day following the freeze. The interval between these maxima approximates the average interval of time between cyclones.

In winter, the average frequency of precipitation, 0.01 inch or more in 24 hours, is 28 per cent. For the 9-day period of Figure 2, it averages 33 per cent. The greater frequency in these periods is probably due to more energetic cyclonic activity during intervals when freezing temperatures have occurred.

Probability of rain as related to the temperature.—Theoretically the probability of a certain amount of rain should diminish as the temperature falls because of the lowered capacity of the atmosphere for moisture. There are, however, other forces influencing the frequency of rain, some of which vary in harmony with the temperature, obscuring the relationship. One of these, cyclonic activity in lower latitudes, is greater when temperatures are low because the action of the cyclone in drawing air from higher latitudes is one of the factors in the production of low temperatures. Greater temperature contrasts are associated with and probably induce more intense cyclones.

The 2,256 temperatures at 7 a. m. in winter, 1901 to 1925, inclusive, have been distributed as shown at "A" in Figure 3. The records were examined for this period to determine the relationship between temperature and

[1] Following the usual rule for decimals, a temperature of 32.5° is an occurrence of 32° in whole numbers, but the tabulation of occurrences of 32° or below in the Weather Bureau does not include readings of 32.1° to 32.5°, hence there were only 89 occurrences. In this paper, readings from 32.1° to 32.5° have been included because of the larger number of cases afforded the study. Due to slight local variations of the temperature there may be a freeze in the immediate vicinity when the station thermometer reads slightly above 32°.

precipitation occurring in the 12-hour period from 7 p. m. of the same day to 7 a. m. of the following day. The total number of occurrences following each 7 a. m. temperature, to even numbers, is shown in Figure 3 at "B". The frequencies vary with the temperature being great-

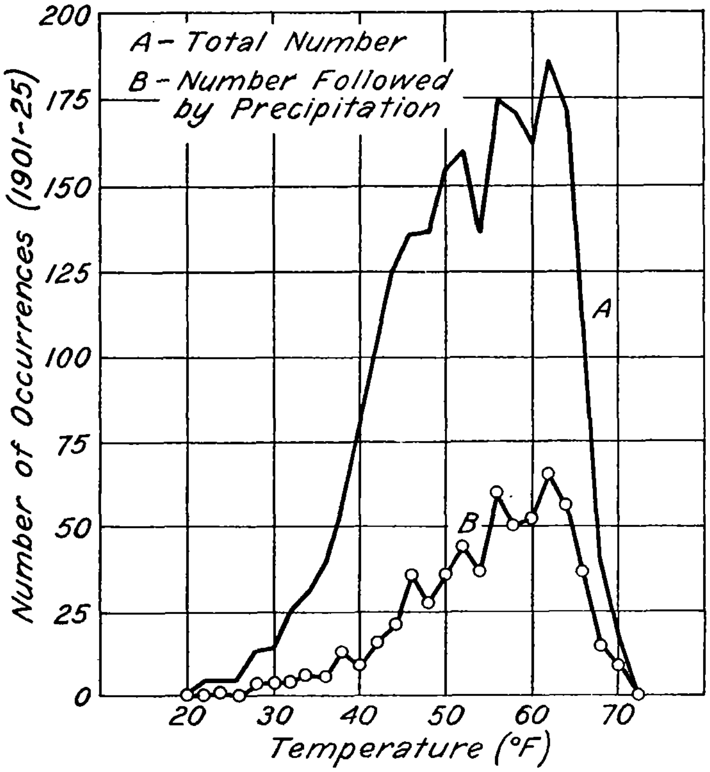

FIGURE 3.—Total number of occurrences of each temperature (to even numbers) at 7 a. m. at Galveston, 1901 to 1925, shown at "A." The total number of such even [1] temperatures, followed in the 12-hour period next thereafter; that is from 7 p. m. of that date to 7 a. m. of the next following date, by precipitation, including traces, shown at "B." Winter temperatures only

est at 62°. However, the probability of precipitation is not thereby indicated since there is greater opportunity for gain following the more frequent temperatures.

To determine the probability that rain will follow the occurrence of a certain temperature, it is necessary to find the ratio between the whole number of such temperatures and the number followed by precipitation. This being done, the probabilities, in percentages, are averaged for groups, with five even readings in each group and the results are shown in Figure 4. The probability increases with the temperature. In the upper curve, all amounts, including traces and 0.01's, are included; in the lower curve amounts less than 0.02 inch are excluded. It will be seen that at temperatures 22° to 30°, the average intensity of precipitation in the following period, 7 p. m. to 7 a. m., seems to be low, there being only 4 per cent probability that amounts greater than 0.01 inch will occur.

At temperatures below 32° there is small likelihood that precipitation will occur in quantities sufficient to make a forecast of fair weather unsuccessful.[2] It has been shown that precipitation occurred on 36 per cent of days with minimum temperature at or below 32° but there have been only seven instances from a 25-year record of precipitation extending into the second day of freezing, the high frequency on the first day being due to rain falling in the same 24-hour period but before the temperature had fallen to the freezing point.

After the temperature has reached 32° it is quite rare that precipitation is recorded. Of course the temperature does not remain continuously at 32° thereafter; on the average day with a minimum at or below 32° considerably higher temperatures are sometimes recorded and readings somewhat higher always occur. The amounts that do fall after 32° is reached are usually small and in the form of sleet, light snow, or a mist or fine drizzle of rain.

The intensity of precipitation is greatest in the warm months and least in cold months (**5**). The intensity of rainfall, though with numerous exceptions, varies with the temperature of the dew point. In a discussion of the distribution of excessive precipitation, Henry (**6**) remarked:

> The higher the temperature of the air, the greater its capacity for water vapor, whence it follows that the precipitation must be more frequent and in larger amount in those regions having the higher dew point.

Conversely, a greater time is required for a given amount of rain to fall in cold periods than in warm, and hence the period of attendant cloudiness is extended, and with it the period over which daytime temperatures are

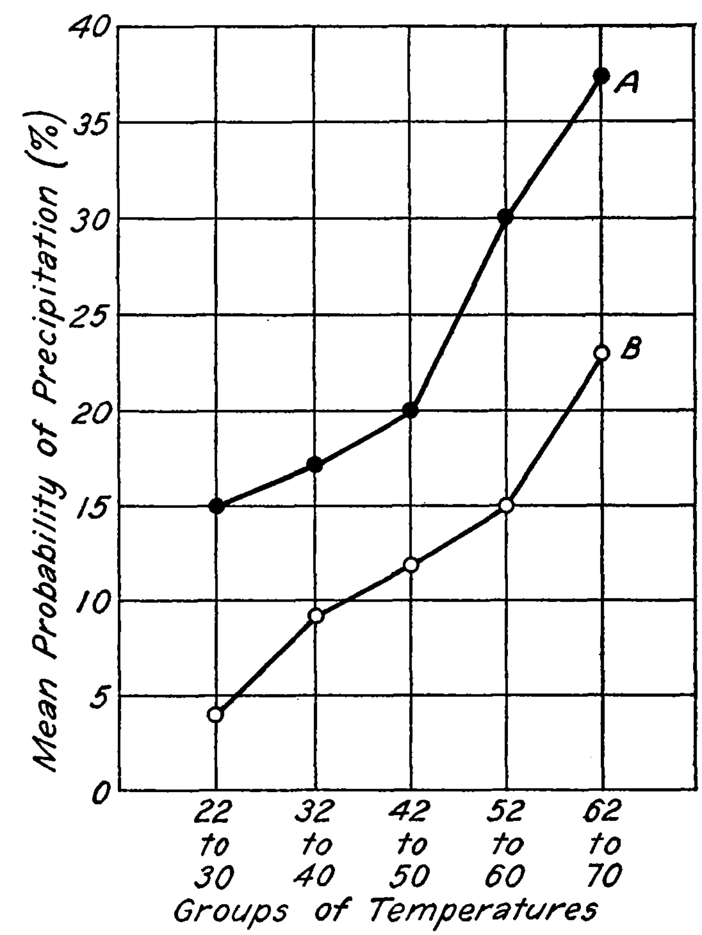

FIGURE 4.—Probability of rain as related to the temperature. A, probability in per cent that precipitation, traces and 0.01's included, will follow a 7 a. m. temperature in the group indicated, in winter, prepared from records at Galveston, 1901–1925. B, probability of precipitation, including only amounts greater than 0.01 inch.

lowered by the cloudiness and precipitation and directly or indirectly the night time temperatures. Wet periods are therefore associated with average temperatures below the normal and dry seasons with relatively high temperatures.

[1] All temperatures are included but the record is in degrees and tenths, and the nearest even temperature is used, whole numbers, following the rule that when the temperature is exactly odd, the next lower number is used; that is, 31 becomes 30.

[2] A forecast of rain, by Weather Bureau rules, is verified on the occurrence of precipitation in any amount, but a fair weather forecast is defeated only when precipitation exceeds 0.01 inch.

Is warm weather dry and cold weather wet?—It has been shown that the probability of rain is greater when the temperature is high than when it is low. To reconcile this conclusion with the fact that temperature departures are generally negative in wet periods, the records from 1875 to 1928, inclusive, of mean monthly temperatures were grouped according to the magnitude of departures from the normal. The values for months prior to 1875 were not used, since the means for some of those months were determined from the means of the 7 a. m., 2 p. m., and 9 p. m. observations, whereas the calcu ations thereafter were from the maxima and minima. The normals used were those adopted in 1922 and the departures from old normals as entered in the records were disregarded. Records of winter months were used and months grouped according to departures of mean temperature from normal as follows: From 0.1 to 2 above normal, from 2.1 to 4 above normal; from 0.1 to 2 below normal, etc. Total monthly catches of precipitation were averaged for the groups so arranged. The results are exhibited in Figure 5.

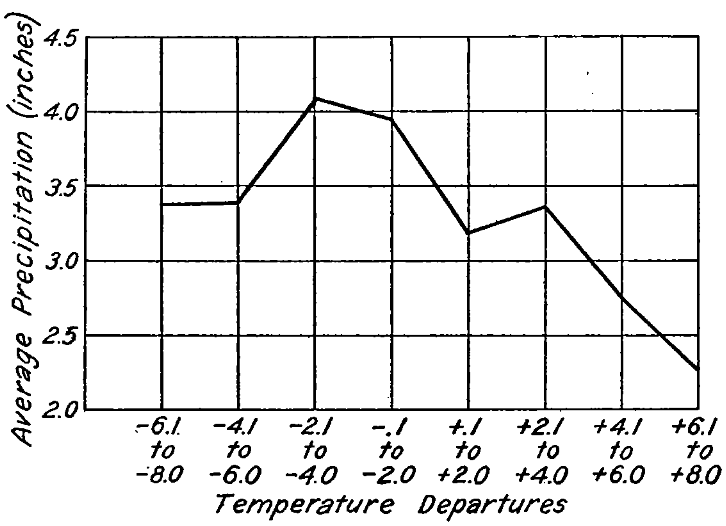

FIGURE 5.—Average rainfall in months with similar temperature departures, arranged in 2° divisions, for winter months, 1875–1928, at Galveston. February amounts were corrected to 31-day total.

An inspection of this curve shows that the rainfall roughly increases as the temperature falls. There is a slight discrepancy here in the spacing of the ordinates, since the central division in reality represents a temperature difference of only 0.2° whereas the remaining ordinates are in divisions of 2°. The maximum rainfall occurs at temperatures slightly below the normal and with further lowering of the temperature the rainfall diminishes again.

The cloudiness which attends frequent precipitation and the falling of rain both tend to lower the temperature, particularly in the day time. When rain is frequent or heavy greater cyclonic activity is indicated which in turn suggests more frequent and more vigorous invasion of cooler air from higher latitudes.

During the years 1875–1928, there were 29 months with temperature 32° or below on three or more days and during these months the rainfall averaged 3.36 inches. The normal monthly fall for that period is 3.33 inches. There were 22 months during which the temperature fell below 25° and during those months the rainfall averaged 3.22 inches or only slightly below the normal of 3.33 inches.

The occurrence of one or more cold waves during the month seems to have no material effect upon the rainfall. The probability of rain in the immediate future seems to be less when temperatures are low but this effect is probably counterblanced by the increased ra nfall due to cyclonic activity preceding the cold wave. As shown by monthly averages, rainfall and attendant cloudiness lower the temperature and thus temperatures slightly below normal become associated with rainy weather.

The cyclonic depression causes high temperatures in advance of its center and thus high temperatures are as a rule indicative of the rain which attends the depression. When the cold or cool wave arrives at the rear of the depression, the continental winds are relatively dry and the capacity of the atmosphere for moisture is lower. Hence the lower the temperature the less is the likelihood of rain in the near future. The relation shown in Figure 4 must be borne in mind in forecasting wet northers. When the temperature is near the freezing point, precipitation occurs only when the distribution of barometric pressure is exceptionally favorable.

Pressure indications.—A HIGH over the Great Plains extending southward into Texas or over the Rocky Mountains or upper Mississippi Valley reaching into the Great Plains and thence into Texas, seems to be an essential feature of the pressure distribution attending wet northers. Frequently the dry norther is merely the wind at the rear of the LOW with no appreciable high pressure development following, and it is then of short duration. There have been occurrences, though quite rare, of precipitation continuing in the northerly winds of the rear semicircle of a LOW with no marked high pressure to the northward, and such a LOW usually moves slowly. A well-defined high-pressure area is nearly always a feature and it is invariably present in the severe type of wet norther. Its function is clearly the transference of cold air southward to produce the necessary temperature contrasts for continued precipitation.

It is generally conceded that precipitation under these circumstances is caused by the overriding of a moist southerly wind above the cold surface norther. Though observations of the upper air bearing on this question are limited in number there is considerable evidence supporting this conclusion.

Brooks (**7**), presented a diagram representing conditions responsible for the formation of various types of snow, sleet, glaze, etc., with a relatively warm southerly wind flowing over the chilly northerly winds. He noted also a convective layer, where conditions are favorable for precipitation.

Meisinger (**8**), after an exhaustive examination of conditions attending the widespread sleet and glaze storm of January, 1920, concluded that,

> * * * One of the major premises of a sleet forecast is the presence in the southeast of a "high," the temperatures within which are not so low as usual, just off the coast of southeastern United States. Such a condition persisted until the last few hours of the period. (January 20–26, 1920.) Moreover, the belt of high pressure, evidently centered far north in Canada, gave an abundant supply of cold air, sweeping down from the deep snow fields of the north far into the United States toward the general area of low pressure along the southern coast. The return flow of warm, moist air, riding over the wedgelike encroaching north wind, was cooled and forced to precipitate rain, sleet, or snow, over most of the eastern United States throughout the period.

These conclusions were in agreement with those of Frankenfield (**9**), who earlier stated the conditions that were favorable for sleet and ice storms, one of them being the presence of moderately high pressures and high temperatures over the East Gulf and South Atlantic States.

Since sleet or glaze accompanied five of the seven wet northers listed in Table 1, it may be assumed that a warm overflow is present in the wet norther of Texas, and that the only difference between the storm that produces sleet and glaze and the other that causes only a cold rain is in the temperature of the surface layer and of the southerly wind, overriding it. When pressures in lower latitudes favor a persistent, opposing southerly wind, and a HIGH to the northward causes a northerly wind with low temperature, rain begins as soon as the surface wind has shifted to northerly, as a rule, and continues until either the surface wind has shifted back to southerly again and its temperature rises due to change of pressures over the interior or until the opposing wind fails due to changes in the pressures in lower latitudes. When the temperature is sufficiently low in the surface layer, precipitation is in the form of sleet, snow or freezing rain, though the exact temperature essential for these conditions varies over a range of several degrees, probably due to varying temperature of the products of condensation at their point of origin and to the thickness and warmth of that portion of the warm layer traversed as well as the thickness and coldness of the cold layer.

Since the high pressure over the interior is present in both, it is evident that a basis of differentiating the wet from the dry norther must be sought in the pressure distribution over lower latitudes.

In seeking critical pressures over lower latitudes, I have examined barometric readings for approximately 200 northers of various intensities, in the period 1901–1925. The most marked and consistent differences were noted between pressures over the Florida Peninsula and along the southwestern border, best represented by readings at Key West and Phoenix. When pressure is higher in winter over the Florida Peninsula than in Arizona, the norther is likely to be wet and vice versa. The pressure contrast at these two stations yields a higher forecast verification than any other. As a test I have taken at random the first 100 maps, showing a winter HIGH over the Great Plains and cold northerly winds reaching the Texas coast or giving promise of doing so shortly. The forecast was verified on the occurrence of precipitation during the 24-hour period from 7 p. m. of the same day to 7 p. m. of the following day. Cases in which the pressures at Key West and Phoenix were identical were disregarded. Including all cases, with difference of 0.02 inch or more, the verification was 72 per cent correct. Including instances in which the difference was 0.10 inch or more, 61 in all, the verification was 84 per cent. Including only those cases in which the difference was 0.20 inch or more, verification was 93 per cent, there being one failure in 14 forecasts.

Considering the fact that the barometric readings at only two stations are used, this is a remarkably high verification. Of course the distribution of pressure is limited to those cases in which a "high" appears over or near the Great Plains causing northerly winds over Texas, or giving every promise of doing so. The conditions necessary for the arrival of the norther on the Texas coast have been discussed by the writer in a previous paper (**10**).

During the sleet and glaze storm studied by Meisinger and previously referred to, January 20–26, 1920, a typical wet norther prevailed at Galveston. Temperatures, however, were not low enough for sleet or glaze. At Galveston precipitation began shortly before the wind shifted to northerly, pressure being considerably lower at Phoenix than at Key West, and having been so during the preceding 24 hours. Northerly winds with intermittent rain continued at Galveston and the pressure at Phoenix was lower than Key West until some time between the p. m. observation of the 23d and the a. m. observation of the 24th, when it became higher at Phoenix. Rain ceased at Galveston about 1 a. m. January 25.

A study of the exceptions to this rule leads to the conclusion that what is needed is the pressure at a point about the longitude of Phoenix and the latitude of Key West.

In the absence of such a datum, there are other conditions, apparently indicative of rain, though not consistently so. One of these is high pressure over the States of Nevada, Washington, and Oregon. Low pressure centered near Seattle is decidedly unfavorable for the development of a wet norther in Texas, as is low pressure in the Lower Mississippi Valley. A LOW in the west Gulf is apparently blocked by the HIGH to the northward when pressures at Vicksburg and New Orleans are higher than at Galveston and Corpus Christi and rain is indicated in the immediate future, this being true only when the HIGH has advanced well into the plains and northerly winds extend over Texas.

The most valuable index, aside from the pressures at Key West and Phoenix, is the barometric tendency at

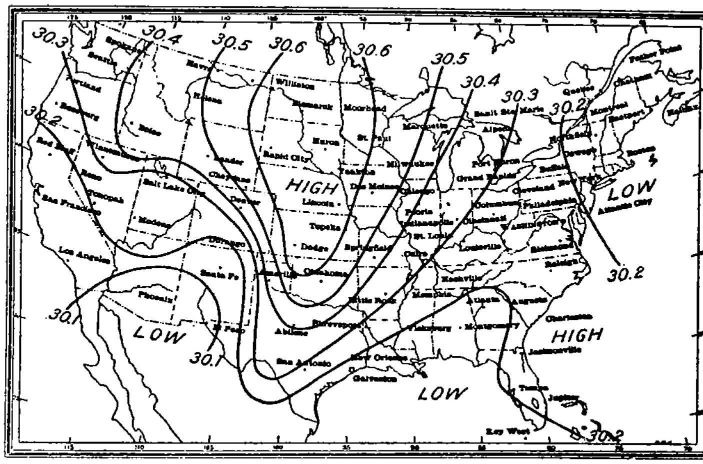

Figure 6.—Composite pressure map for six severe wet northers at Galveston. Dates are those shown in Table 1, the map for January, 1912, norther not being available. The barometric conditions shown are immediately preceding the norther

those places. Especially when the pressure differences between these points is slight, the 12-hour changes must be given consideration. While high pressure over Florida, as indicating, perhaps, the strength of the South Atlantic HIGH, is a sign of a wet norther, other conditions being favorable, it is not the actual pressure, as being above the normal for that region, but the *relative* pressure as compared with conditions in the far Southwest that presages the continuance of an opposing southerly wind.

One is therefore led to the conclusion that failure to understand some of these exceptional cases is due partially to the fact that our Southwestern field of observation does not extend far enough to the southward to give a complete solution to the problem.

Typical cases of wet and dry northers are exhibited in Figures 6 and 7. The first is a composite of the severe wet norther maps, as listed in Table 1, that of January, 1912, missing. The second is a composite of the five maps for dates shown in Table 3, in which two or more days with freezing temperature occurred without precipitation and were not preceded by a day with precipitation and freezing temperature. The dry norther of December 31, 1927, being of this class, was also included to make the number equal to that of the wet northers.

CONCLUSIONS

1. Severe wet northers, with two or more consecutive days with freezing temperature and precipitation, occur in the vicinity of Galveston about once in three or four years.

2. The probability of rain is least on the day following the freeze and greatest on the day preceding.

3. The higher the temperature in winter the greater is the probability of precipitation, based on occurrences during the following night period.

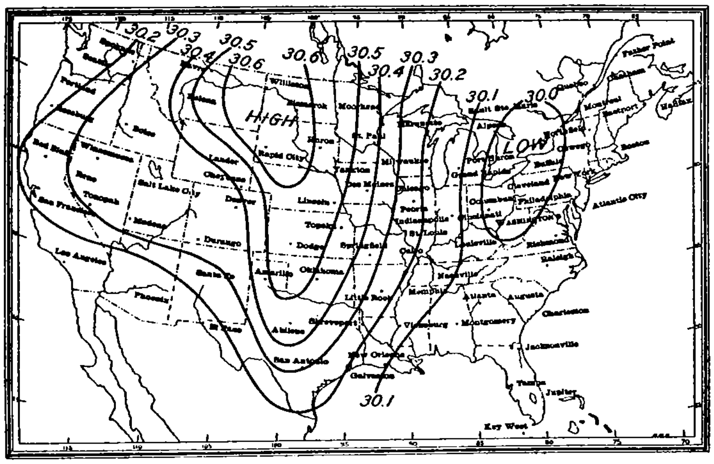

FIGURE 7.—Composite pressure map immediately preceding six outstanding dry northers at Galveston. They include those of Table 3, omitting the northers preceded by one day of freezing with precipitation and including the dry norther setting in on December 31, 1927

4. Cooling, due to cloudiness, rain, and more frequent northerly winds, causes temperatures to average below the normal in wet weather.

5. At temperatures below freezing the average intensity of precipitation is low and probability of its occurrence slight.

6. Dry northers are winds to the rear of low-pressure areas with or without high pressure to the northward and are characterized by higher pressure at Phoenix than at Key West when the HIGH is the dominant factor.

7. Wet northers are winds from high-pressure areas over the Great Plains or adjoining sections, overridden by warm, moist, southerly winds. They are characterized by higher pressure at Key West than at Phoenix.

8. Other conditions favoring the wet norther are high pressure extending westward through Nevada, Oregon, and Washington, pressure tendency downward at Phoenix and upward at Key West, and relatively high pressure in the Lower Mississippi Valley.

9. Other indications of the dry norther are the reverse conditions—low pressure centered near Seattle or thereabouts, pressure tendency downward at Key West and upward at Phoenix and a well-defined depression in the Lower Mississippi Valley.

10. Southwestern reports should extend to approximately the latitude of Key West.

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LITERATURE CITED

(1) Dampier, William. Dampier's Voyages. 1906. (E. Grant Richards, London.) Vol. II. pp. 280–284.

(2) Chapel, L. T. Winds and Storms on the Isthmus of Panama. Mo. Wea. Rev., Dec., 1927. 55 : 526–527.
Frankenfield, H. C. "Forecasts and Warnings for November, 1917." Northers of the Canal Zone. Mo. Wea. Rev., Nov., 1917. 45 : 546.
Blair, T. A. Northers of the Sacramento Valley. Mo. Wea. Rev., Apr., 1909, 37 : 132.

(3) U. S. Signal Office. The Climatic Conditions of Texas, Especially with Reference to Temperature and Rainfall. War Dept. 1891. pp. 16–18.

(4) U. S. Weather Bureau. Climatological Data for the United States by Sections. Oct. to Dec., 1924. Vol. XI. Texas Section.

(5) Tannehill, I. R. Some Characteristics of Texas Rainfall. Mo. Wea. Rev., May, 1923. 51 : 250–253.

(6) Henry, A. J. The Distribution of Excessive Rainfall in the United States. Mo. Wea. Rev. Sept., 1928. 56 : 357.

(7) Brooks, C. F. The Nature of Sleet and How it is Formed. Mo. Wea. Rev., Feb., 1920. 48 : 69–73.

(8) Meisinger, C. L. The Precipitation of Sleet and the Formation of Glaze in the Eastern United States, January 20 to 25, 1920, with Remarks on Forecasting. Mo. Wea. Rev., Feb., 1920. 48 : 73–80.

(9) Frankenfield, H. C. Sleet and Ice Storms in the United States. Proceedings Second Pan-American Scientific Congress. Gov't Printing Office, Washington, 1917. Vol. 2, pp. 249–257.

(10) Tannehill, I. R. Severe Cold Waves on the Texas Coast. Mo. Wea. Rev., Feb., 1928. 56 : 41–46.